SPACE STATION DOCKING MECHANISM DYNAMIC TESTING

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Abstract

A prototype docking mechanism for the Space Station has been designed and fabricated for NASA. This docking mechanism is actively controlled and uses a set of electromechanical actuators for alignment and load attentuation. Although the mechanism has been extensively modeled analytically, a series of dynamic tests will be performed for validation. These dynamic tests will be performed at the NASA Marshall Space Flight Center's 6-DOF Motion Simulator. The proposed tests call for basic functionality verification as well as complete hardware-in-the-loop docking dynamics simulations.

Introduction

Over the past 25 years, the American space program has used only two basic classes of docking mechanism. Namely, the "probe-drogue" type, and the "clear pass-through" type. The probe-drogue concept was utilized on the Gemini, Apollo and Skylab projects. The pass-through concept was successfully used on the Apollo-Soyuz Test Project (ASTP) and is the type of docking mechanism being considered for Orbiter to Space Station docking.

The Space Station docking mechanism, shown in Figure 1, is the first fully actively controlled docking mechanism to be used by the United States. The active mechanism uses a set of eight electromechanical actuators to perform such tasks as capture, load attenuation, and alignment/retraction. In the typical docking scenario, two sets of latches are used. A set of "quick-acting capture latches" are used to quickly secure the two halves of the mechanism together after the initial contact. After all relative motion between the Orbiter and the Space Station has been dissipated, a set of 16 "structural latches" mechanically lock the two mechanism halves together.

The size of the docking port, as well as the performance capabilities of the mechanism have been modified over the past two or three years. The prototype geometry used by McDonnell Douglas, who designed the system for NASA, is shown in Figure 2. This geometry reflects the requirements of the docking mechanism as of 1985.

Analytical contact dynamics models of the docking mechanism were incorporated into several multibody simulations so that the effectiveness of various control schemes could be measured. A "good" docking mechanism can be defined as one which has a large capture envelope, minimizes the contact and attenuation loads, and can complete the docking sequence time initial contact to structural latch quickly. The analytical contact dynamics tools developed for the docking mechanism were essentially the only means of judging the performance of various controllers proposed for the mechanism.

As a means of validating the docking mechanism, a set of dynamic tests will be performed on the prototype mechanism. These tests will take place at NASA's Marshall Space Flight Center's 6-DOF Motion Simulator. It is expected that these tests will verify much of the analytical work previously mentioned, and at a minimum the tests should provide insights to certain modeling deficiencies which are unobtainable elsewhere.

Analytical Studies

Before evaluation of various candidate controllers of the docking mechanism could begin, two basic tasks had to be completed. The first was the establishment of a capture envelope, i.e. misalignments, inside of which the mechanism must successfully dock. The second task was the analytical formulation of the forces and moments generated by contact of the two mechanism halves, i.e. a contact dynamics model.

The capture boundaries shown in Table 1 have been generated primarily by man-in-the-loop proximity operation simulations located at JSC. (Ref. 1) The values listed in Table 1 essentially reflect the accuracy to which the pilot can control the Orbiter during a rendezvous with the Space Station.

Before developing the contact model for the docking mechanism, a review of previous work was made. Bodley applied Hamilton's principle to the probe-drogue contact problem. (Ref. 2) However, the significantly more complex geometry of the current docking mechanism (as compared to probe-drogue) make the use of Hamilton's principle rather unattractive. TRW developed a general contact model around 1970 (Ref. 3) which attacked the problem by modeling the geometry of one body as a set of nodes which may contact a surface on another body. Since either half of the "pass-through" docking mechanism has a great deal of surface area which may contact the other half, a very large number of points would be required for a high fidelity contact model. Thus, it was decided to formulate a contact model specifically for the mechanism under consideration, rather than modify a previous model.

The basic approach to formulating the contact model was to consider each type contact that could occur with the mechanism separately. (Ref. 4) The three basic types of contact that can occur with the "pass-through" type docking mechanism are: 1. docking ring to docking ring, 2. docking ring to guide, and 3. guide to guide. Instead of using a set of Lagrange multipliers to enforce geometric constraints, a "soft-constraint" (Ref. 5) method was employed. The soft-constraint method, which is analogous to penalty methods used in finite element analyses, places a reacting force at the point of contact whose magnitude is proportional to the penetration distance.

This is similar to the action of the Lagrange multipliers; however, with the soft-constraint method there are no Lagrange multipliers to be calculated.

Once the contact model was formulated, coded, and checked-out it was placed in a multibody simulation for use in parametric studies of control law parameters. A detailed discussion of the control law development is beyond the scope of this paper, however, the results of the study are germane. It was found that if the 8 electromechanical actuators were controlled in such a way that they effectively represented a 10 lb/ft axial spring, capture is assured if the minimum closing velocity is kept above 0.05 ft/sec and the misalignment is within the envelope specified in Table 1. A small amount of viscous damping (rate compensation) was given to each individual actuator through its own analog control loop to enhance the capture performance, e.g. reduce the amount of "chattering" the mechanism undergoes during the capture phase.

Dynamic Test Strategy

While the analysis of the docking mechanism has been indispensable as an aid to the design of the mechanism and its controllers, only a dynamic test can verify the functionality of the system. Of course, if the test results agree with the analytical predictions then the models can be used with confidence as predictive tools in other studies. A series of five tests are planned for the mechanism at MSFC. The first four tests are basically the system checkout tests, while the final test actually puts the mechanism through a number of complete docking sequences.

The first test to be run at MSFC is a latch test. The purpose of this test is to insure the quick-acting capture latches are functional. The second test is a control system function test wherein the docking ring on the active mechanism half is commanded to various positions from the control computer. The third test to be performed is the capture mode response test. For this test, the active mechanism will be placed into the capture mode from the control computer. The effective spring provided by the 8 electromechanical actuation should be 10 lb/ft in this model. The value will be verified. Test four is a mate and latch test, the purpose of which is to verify that the mechanism is stable after the capture latches have been thrown. If a stability problem is detected a frequency response test will be performed to identify the problem.

The final test is actually a series of full contact dynamic tests using the MSFC 6-DOF motion simulator. A total of 64 cases will be run, each of which have different misalignments between the mechanism halves at contact. The 64 cases have been selected such that they explore the envelope represented by Table 1. The 6-DOF simulator has the capacity of representing the dynamics of the orbiting bodies in near proximity. This capability will be discussed in detail in the next section.

Test Facility Description

The dynamic testing to be performed with the prototype Space Station docking mechanism will be performed at the Marshall Space Flight Center's 6-DOF Motion Simulation Facility. The basic layout of this facility is illustrated in Figure 3. The active half of the docking mechanism will be mounted to the 6-DOF table, and the rigid half will be attached to the force/torque sensor which is mounted to the ceiling.

The 6-DOF facility basically works in the following way. The software residing in the VAX contains a dynamic representation of the orbiting vehicles. The software is aware of the contact forces acting on the two vehicles at all times, and is therefore able to compute what the relative position and orientation of the vehicles should be. This relative position data is converted to actuator lengths and sent to the 6-DOF table which attains the correct position by moving the 6 hydraulic actuators in concert. The forces and moments generated by contact between the two bodies are measured by the force/torque sensor from which the rigid half of the docking mechanism is suspended. The output of the force/torque sensor is continuously fed into the VAX, thus closing the loop between interacting contact forces and relative motion between the two vehicles.

The 6-DOF software requires the mass properties of the two vehicles, which will be those of the Space Station and the Orbiter for the tests being discussed. The initial conditions that the 6-DOF requires will be generated for each of the 64 dynamic test cases discussed in the previous section.

The analog signals generated by the 6-DOF system, such as force/torque sensor output and actuator lengths, can be made available to a bank of strip-chart recorders. All data processed by the VAX, e.g. relative positions and orientations, can be output to a standard plotting package for review after a test is complete.
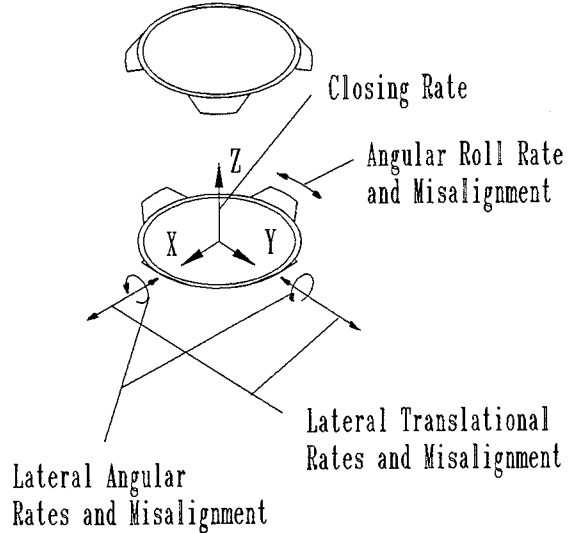
Conclusion

A "pass-through" type of docking mechanism has been designed for use during Orbiter to Space Station docking operations. The half of the mechanism that is carried on the Shuttle is actively controlled, using a set of 8 electromechanical actuators to provide the necessary alignment and load attenuation capabilities.
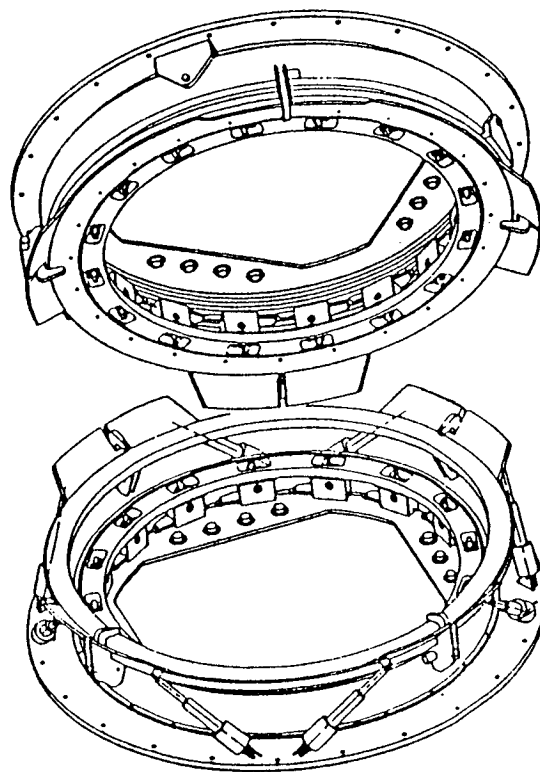
Although the mechanism has been the subject of a great deal of analytical modeling, a dynamic test of the mechanism is needed to verify its capabilities. These dynamic tests will be performed at the MSFC's 6-DOF Motion Simulation Facility. This real-time simulation facility has the capability of simulating the dynamics of a pair of orbiting vehicles which are undergoing contact

References

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TABLE 1

DOCKING CONTACT ALIGNMENT EXTREMES	
Closing Velocity, m/s (f/s)	0.06 (0.20)
Lateral Velocity, m/s (f/s)	+/- 0.02 (0.06)
Angular Velocity, deg/s	
-- Roll	+/- 0.05
-- Lateral	+/- 0.15
Lateral Misalignment, m (in)	+/- 0.11 (4.5)
Angular Misalignment, deg	
-- Roll	+/- 3.0
-- Lateral	+/- 4.5
Relative CG Velocity, m/s (f/s)	
-- Closing	0.06 (0.21)
-- Lateral	+/- 0.02 (0.07)

Closing Rate

Angular Roll Rate and Misalignment

Lateral Translational Rates and Misalignment

Lateral Angular Rates and Misalignment

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RIGID HALF MECHANISM
ATTACHED TO SPACE STATION

ACTIVE HALF MECHANISM
ATTACHED TO ORBITER
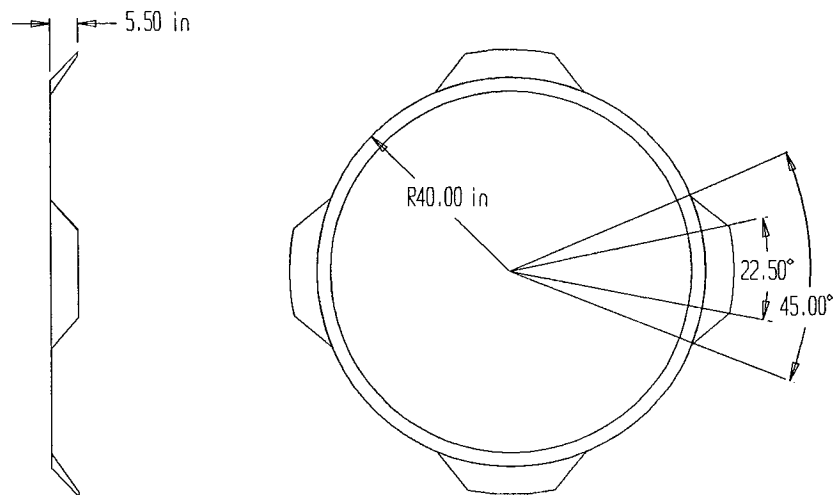
FIGURE 1. Proposed Space Station Docking Mechanism.

5.50 in

R40.00 in

22.50°

45.00°

FIGURE 2. Geometry of Docking Mechanism.

Figure 3. MSFC 6-DOF Motion Simulation Facility

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Session V

SPACE SIMULATION I